DIAGNOSIS OF OCCLUSAL CARIES USING VISUAL EXAMINATION, CONVENTIONAL, DIGITAL RADIOGRAPHY AND LASER FLUORESCENCE

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Declaration of Authorship

I, Michael Chong of 10 Ludlow St, Chapel Hill, Queensland, do solemnly and sincerely declare that these Research Project Reports have been composed by myself and have not been accepted in part or in full for another degree. I make this declaration conscientiously believing that the same to be true, before a Justice of the Peace.

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PREFACE

With the greater availability of primary and secondary sources of fluoride, general caries prevalences have declined in Western countries in the last few decades. Occlusal caries now accounts for the majority of new carious lesions in young children. Suspicions have been raised in regard to the increasing observation of occlusal caries being radiographically identified in dentine however appearing clinically intact on its occlusal surface. Previous studies have confirmed this and some of these studies have implicated fluoride to play an important part. Additionally the realisation that traditional methods of caries diagnosis, notably the mirror and explorer and radiography, are not as accurate as once previously thought. With ever-increasing advances in technology in the field of dentistry, there is a growing variety of methods for the detection of occlusal caries. Such methods include digital radiography, electrical resistance measurement, transillumination and quantitative light-induced fluorescence. This research project was therefore undertaken to determine both the usefulness of each method and to compare the sensitivity and specificity of selected methods in the detection of occlusal occult caries on extracted premolar teeth. Scientific paper I reviews current clinical methods of occlusal caries diagnosis, and is presented here in the format for the Pediatric Dentistry Journal in which publication is intended. Scientific paper II documents the research report, formatted for submission to the Pediatric Dentistry Journal.

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Abstract

The increased prevalence in diagnosis of occlusal occult lesions may be a reflection of the changing attitudes of modern dentistry. In a period where caries prevalence rates have declined in the past 20 years, more emphasis is now placed on prevention rather than restoration of the disease. Therefore occult caries are being diagnosed earlier by radiographic methods where the demineralisation may be confined to the enamel stage, as compared to clinically diagnosing advanced caries where gross occlusal caries has progressed. Traditional methods based largely on tactile-visual examination have been recognized as being inadequate methods in the diagnosis of occult caries and there has been increased enthusiasm for new techniques that are available to clinicians and researchers. This review discusses diagnostic methods available in the detection of occlusal occult caries such as quantitative light-induced fluorescence, conventional and digital radiography, electrical resistance measurement, fibre optic transillumination, visual inspection and tactile examination. A comparison and assessment of the various methods are made, plus advantages and limitations of each technique are discussed.

Introduction

In 1983 Newbrun described the activity of dental caries as an active process involving four variables including the tooth surface, diet, bacteria and time in the carious process. The modifications of these variables such as plaque activity, results in the equilibrium between demineralisation and remineralisation, the tooth surface and surrounding plaque fluid. This equilibrium results in a lesion being either rapidly progressing, slowly progressing or arrested [1].

Dental caries starts as clinically undetectable subsurface demineralization of enamel, visible only by microscopic techniques, and proceeds to the advanced lesion with surface cavitation that can be recognized by the clinical examiner[2]. At the earliest clinically detectable stages, progress can be arrested, avoiding the need for operative intervention[3]. Existing methods of caries diagnosis is limited in detecting early lesions where it is still confined to the outer enamel [2]. Traditional methods of caries diagnosis include the combination of visual examination, probe and conventional radiographs. More recently other qualitative and quantitative methods have become more widely used and include techniques such as electrical resistance measurement, light induced fluorescence, fibre-optic transillumination and digital radiography.

The caries prevalence in Western countries in the last 20 years has declined[4,5]. This is most likely attributed to a number of factors, most notably the greater availability of primary and secondary fluoride sources such as fluoridated water supply, toothpastes [6,7], and food products containing fluoride. It has been shown that the greatest benefits of fluoride are exhibited on smooth surfaces of teeth. Inevitably there is an increasing proportion of occlusal caries [5,8-10] and it now accounts for the majority of caries in the 8-15 year old group[11-16]. Wenzel et al 1993[4] stated that occlusal surfaces are twice as likely as approximal surfaces to be affected by caries.

Additionally occlusal caries accounts for the majority of new caries in young children[2,12,17]. The US public Health Service 1981 found that 84% of the caries experience is occlusal in nature in 5-17 year olds[18].

An explanation for the increasing proportion of occlusal caries may lie in the inadequacy of traditional diagnostic methods. These methods of caries detection, particularly of the occlusal areas are limited in three ways: 1) detection of caries is only possible once the lesion has progressed to an advanced stage where operative intervention is necessary[19], 2) quantification of the amount of mineral loss in tooth structure is not possible, 3) observation of small changes in tooth structure is difficult[20]. Using the current diagnostic techniques, detection is difficult for occlusal surfaces[8,21,22].

It is understood that the lesion progresses in three dimensions following the direction of the dentinal tubules. Studies have confirmed the characteristic lateral spread of caries along the DEJ once it has progressed into dentine. This occurs only at the advanced stage[23]. Ekstrand and coworkers 1995[24] examined macroscopically, stereomicroscopically and radiographically, the signs of the progressive stages of caries in relation to the histological features of the occlusal in extracted maxillary third molars. They noted that dentine demineralisation never occurred before contact between the enamel lesion and the enamel-dentine junction, as was previously assumed[25,26]. This agrees with observations by Bjorndal and Thylstrup 1995[23] regarding the progressive stages of approximal caries lesions.

Additionally, accurate diagnosis of occlusal caries remains difficult because of the presence of the initial lesion on the tooth's fissure walls[27,28] as compared to the entrance of the fissure. Juhl 1983[29] showed that in extracted premolar teeth 61 percent of early lesions occurred on the walls of the fissure near its base, an area hidden from direct view. Ekstrand and Bjorndal 1997[30]

have shown that lesion progression rate is faster at the entrance to the fissure due to microorganisms being metabolically active in these parts, as compared to the base of the fissure. In addition the fissure provides an area for plaque stagnation near the entrance to the fissure for the organisms present to survive[1].

The occlusal surface has more complex anatomical morphology than other coronal parts of the tooth. Consequently more complex light scattering patterns from the enamel and dentine lead to poor contrast between demineralised and undermineralised tooth tissue[31] thereby making visual diagnosis difficult.

Hidden caries

Recently there has been concern over the difficulty in identifying occlusal caries clinically, that are present radiographically. This phenomenon has been termed "hidden caries"[32]. Other terms for this occurrence include "occult caries", "overt caries", "fluoride bombs" and "fluoride syndrome"[32]. "Pre-eruptive intracoronal resorptive lesions" can be seen when a radiolucent defect is evident in a previous radiograph of the affected tooth with an occult lesion. Once the tooth has erupted it has the same clinical and radiographic appearance as an occult lesion.

It has been suggested that the prevalence of pre-eruptive resorptive defects contributes to about 50% of the total prevalence of occult caries[33-40]. The prevalence of occult caries as cited in the literature is variable and is mostly dependant on the criteria used by the authors to identify an occult lesion. Prevalence values range from 0.8 percent [41] to 50 percent[35] in mostly adolescent samples. Occult caries appear to be mostly site specific with the highest occurrences appearing in mandibular first molars and first premolars [40]. Occult lesions also show intra-coronal site specificity.

It has also been found that the prevalence of occult caries was strongly associated with ectopic positioning of unerupted teeth. Seow et al 1999[40] showed that 28% of teeth with ectopic positioning were associated with pre-eruptive dentine defects. Racial and gender factors do not appear to play a part.

The nature and etiology of hidden caries still remains unclear. Several suggestions of etiology have been proposed and include developmental and mineralisation problems[42,43], and acquired apical inflammation of the primary teeth. The most likely suggestion is a process of resorption[37,38,43-47]. This is most likely initiated externally from the tooth where a loss of the integrity of the reduced enamel epithelium allows the entrance of resorptive cells such as osteoclasts and chronic inflammatory cells from the surrounding bone[42,47,48] to form an internal dentine defect.

Systemic factors appear to play a minimal role in the etiology, however local factors seem to have a more influential effect. As mentioned previously, there is a positive correlation of hidden caries and ectopic positions of teeth[39]. A possible explanation points to the resultant local damage that is caused by the pressure from the ectopic tooth to the protective covering of the reduced enamel epithelium.

There have been implications in the role of fluoride having a positive effect on the prevalence of hidden caries. Several authors have suggested that the remineralising potential of fluoride on superficial enamel can have a masking effect on dentinal caries[21,49,50]. Weerheijm and co workers 1997[51] looked at the effect of fluoridated drinking water on the occurrence of hidden caries in the clinically sound occlusal surfaces. This retrospective study used longitudinal data from a Dutch epidemiological study in 1968 that involved two cities, Tiel and Culemborg. The participants in Tiel were exposed to artificially fluoridated drinking water (1.1ppmF) and the participants from Culemborg were not exposed to supplementary fluoride (0.1ppmF). The results of the investigation show a

proportional reduction of surfaces with hidden caries among clinically sound surfaces in the fluoridated area.

Clinical methods of occlusal caries diagnosis

The importance in identifying and diagnosing early enamel caries is significant because alternative treatment options are then available instead of operative intervention. It has been shown that active lesions where the tooth surface is intact may be managed by intensive patient education and professional tooth cleaning[52,53].

When evaluating diagnostic methods for occlusal caries detection, an understanding of the advantages and disadvantages of different methods should be considered. Factors such as precision and accuracy of the methods should be considered where precision refers to the consistency of the results and accuracy refers to the trustworthiness of the results gained. The detection rate of the true positive and true negative results, also known as sensitivity and specificity[54], respectively are then considered. Frequent false positives results (high sensitivity) lead to unnecessary removal of sound tooth structure, however tests that are biased towards higher specificity may result in caries being undiagnosed. The review will discuss seven most commonly used techniques.

<u>Visual inspection</u>

The visual examination method is undoubtedly the most common and easiest method used in the detection of occlusal caries. However the accuracy of diagnosis that is achieved is quite low with sensitivity values below 30 percent[8,55-60]. This indicates that there are a high percentage of undetected occlusal fissures. When the visual technique is used alone 1.2-32.2 percent of the total dentine lesions of occlusal surfaces remains undetected[34,35,41,55,61-63]. Even clinically intact fissures with no obvious enamel breakdown present record a high percentage of undetected occlusal caries[58,64]. Moreover it has been shown that

discoloration in the fissures is not a reliable indicator of the dentine lesions[56,60,65,66].

In contrast, several authors have found promising results after air-drying the occlusal surface that is validated histologically [67-69]. Ekstrand and co workers in 1995[24] demonstrated in a laboratory study that macroscopic changes on the occlusal surface were well correlated with the histological penetration depth of the lesion ranging from lesions confined only to enamel to those that extended well into dentine. In 1997 the same author[70], used a modified version of the visual scoring system. In a laboratory setting they investigated and compared the reproducibility of a 5-point visually ranked scoring system, an electronic caries scoring system, and a radiographic ranked scoring system. Histological sections validated each of the systems' ability to assess lesion depth. Results showed that the new visual scoring system and electronic caries scoring system were highly correlated with lesion depth. Using this visual scoring technique none of the tooth that scored as visually sound had histological evidence of caries effectively resulting in a 100% specificity score.

Ekstrand and co workers 1998 furthered this study when the study was carried out on erupted wisdom teeth destined for extraction. This allowed clinical evaluation of the teeth with histological validation to assess the activity of the lesion[68]. One hundred percent specificity values were obtained once again for visually sound and ECM recordings when correlated with radiographs. Strong relationships were observed using Spearman rank-order coefficient (S_p) between histological lesion depth and visual criteria (S_p =0.75, $p<0.0001$), ECM classification (0.71, $p<0.0001$) and radiographic scores (0.81, $p<0.0001$). Additionally by using methyl red dye and polarized light microscopy to assess lesion activity, visual scores, ECM readings and radiographic readings related statistically to histological lesion activity.

Despite their success in the laboratory studies Ekstrand et al [70] mentioned that the visual scoring system may be impractical for routine clinical use.

The favorable results of some of these studies with visual inspection may be explained by simple refractive index physics. Demineralised tooth structure is porous and these spaces are filled with water when the tooth is wet. When the tooth is air-dried these spaced are filled with air instead. The difference in refractive index between dry demineralised tooth and wet demineralised tooth is greater. Therefore it is easier to detect the lesion with air dried teeth, so less advanced lesions can be detected visually.

The use of the visual inspection technique in diagnosing occlusal caries has been shown to be accurate in laboratory conditions. However for clinical situations, the literature suggests that it should not be used as a diagnostic tool in itself. Its application can be utilized as an adjunct to other diagnostic methods. Visual inspection is nonetheless an essential step in occlusal cries diagnosis despite its questionable validity.

Tactile techniques

The explorer and mirror have traditionally been accepted as the method for detecting occlusal caries in the United States. The identification of a sticky fissure using this simple tactile information has been popular due to a number of factors, mostly due to its convenience, and perhaps the assumption that this technique is reliable.

Although a wide range of variation exists, studies have shown that generally probing of the occlusal surfaces demonstrates low sensitivity scores from 14% [56]. Specificity values lie above 82%[8,15,56]. A recent study investigating probing and using histological validation showed that probing for stickiness discovered 24% of carious lesions, and the probe rarely stuck in a sound

fissure[58]. Sensitivity results of 24% and specificity values of more than 99% indicate that many occlusal lesions are frequently missed by tactile methods.

Lussi 1991[8] in an *in vitro* study of extracted molars and premolars compared the accuracy and reproducibility of diagnostic and treatment decisions of fissure caries with and without an explorer. It was concluded that the use of an explorer does not improve the validity of diagnosing fissure caries when compared to that of a visual inspection alone. Additionally, the results showed that lower sensitivity scores were obtained from dentists using an explorer than those without an explorer. Although these results were not statistically significant it may indicate the inclination of dentists to identify caries in a fissure with sticking rather than close visual inspection.

It is interesting to note that recent studies using the probing technique alone as a diagnostic tool are limited and most studies have chosen to eliminate this tool in adjunct with visual inspection. The reasons for this will be explained further.

Many authors doubt the accuracy of this diagnostic technique. The desired stickiness or "very light pull" that traditionally denotes occlusal caries may simply be the result of morphological wedging a sharp probe within a fissure system. The stickiness is dependant on factors such as pressure exerted, the path of insertion and withdrawal, the width of the probe tip and the fissure anatomy[15,58,71]. With many existing variables determining the outcome or stickiness of a fissure there is potential for wide variations in the interpretation from different operators[15,50,71].

There have been attempts at standardization techniques for probing, concentrating on the pressure exerted[72], and calibrating and training examiners[73]. In this case the participants of the study inserted and withdrew an explorer from a rubber eraser, because in the authors' opinion, this simulates the

stickiness of caries very well and also ensured that no excessive pressure was exerted.

Other doubts have been raised concerning the destruction of tooth structure as a result of vigorous probing[74-77] (Bergman 1969 interproximal 0.1-2mm defect in white spot lesions, Van Dorp 1988 (used artificial grooves in bovine enamel). During probing, the pressure and forces applied to explorer, is concentrated into a small point at the tip that will potentially cause destruction. Ekstrand and co workers[75] found that the occurrence and size of the defects caused by the explorer were strongly related to the degree of tissue opacity and degree of mineralisation, which was associated with the surface morphology.

Additionally there has been a suggestion that probing has the potential to physically transmit cariogenic bacteria from a carious lesion to the base of non-carious fissure although the extent to which this is believed is varied[78].

Despite the shortcomings of probing as a diagnostic tool, it should be understood that the value of tactile sensation and probing to augment other methods such as visual techniques are useful. Quite commonly probing can be used to remove debris from fissures or to obtain an idea of the fissure anatomy of partially erupted molars and ectopically positioned teeth. However in the face of current evidence, it is difficult to defend the potential for iatrogenic damage of otherwise remineralisable white spot lesions in fissure walls when using visual-tactile methods.

<u>Fibre-optic transillumination (FOTI)</u>

Due to the increased use of dental radiography from 1957, there has been concern in regards to the safety and exposure of radiation to patients, especially children and young adults[79]. In the last 20 years, FOTI was seen as an

alternative method to bitewing radiography for detecting small interproximal lesions. FOTI has been shown to be a reliable method for detecting dentinal approximal lesions[67] and there has been an increasing use of FOTI in laboratory studies for detecting occlusal caries. FOTI equipment is cheap, transportable, practical and safe and makes this equipment ideal for using in epidemiological studies.

FOTI works on the comprehension that a carious lesion has a lowered index of light transmission; an area of caries appears as a darkened shadow that follows the spread of decay through the lesion [80,81]. The detection of caries is more inaccurate if a wide beam of light is used, because the glare of light eliminates detail of the surface[82].

Many studies have reported that more caries were diagnosed with FOTI than by clinical examination alone[81-89]. Correlations in results between FOTI and clinical investigation has revealed between 50%[86] and 100%[87] correlation. Rock and Kidd 1988[90] showed that when FOTI was correlated with histological examinations in a clinical study, FOTI was of limited value in detecting occlusal lesions. Verdonschot et al 1991[91] demonstrated FOTI technique to have very good specificity of 99% with quite a low sensitivity of 13%. Clinically this would transcribe into the accurate diagnosis of sound surfaces however it will often miss occlusal caries. Other authors have found similar patterns of results. Verdonschot and co workers 1992[60] found that by using drilling into fissures as validation, the positive predictive value of FOTI was superior to that of clinical examination and radiography for detection of small occlusal carious lesions. Although FOTI achieved the highest specificity scores of 0.99 in this *in vivo* study, it also attained the lowest sensitivity scores of 0.13.

In a histologically validated ROC analysis *in vitro* study, FOTI performed more accurately than visual and radiographic detection for the diagnosis of dentinal occlusal lesion for caries in dentine just beyond the enamel-dentine

junction, while radiography was better for deep dentinal lesions[92]. However the use of the FOTI method was under optimal laboratory conditions. In contrast to this other authors have found that FOTI had difficulty in distinguishing lesions located deep in enamel or just into dentine.

Although this technique has been used extensively for detecting caries in approximal areas, more studies are needed to establish the value of FOTI in detecting occlusal caries. The few publications that have reported its use so far have not been promising.

Electrical resistance measurement (ERM)

The integrity of an occlusal area may be evaluated by its electrical conductivity. Pincus in 1951[93] was the first to describe this method for caries diagnosis. Later work in 1964[94] found that sound enamel surfaces should possess little or no electrical conductivity while carious or demineralised enamel should have a measurable conductivity that increases with increasing demineralisation. The change in electrical conductivity has been explained on the basis that microscopic cavities, formed during remineralisation, fill with saliva to form conductive pathways for electrical transmission, thereby the conductivity increases with demineralisation[95,96].

There are two types of instruments that have been developed for electrical caries measurement. The first type was marketed as the Electronic Caries Monitor or ECM, Lode Diagnostic, Groningen, ECR, the Netherlands. Early clinical studies demonstrated its ability to diagnose early lesions accurately and consistently[60,90]. Another commercially available version of ERM was developed in Japan and called the Caries Meter L, Onuki Dental Co. Ltd., Japan. By placing a minimal amount of saline at the site of measurement, the ERM ensures good probe contact.

The results of studies using the Electronic Caries Detector have been encouraging [60,90,95,97]. Similar results have been reported with the Caries Meter [98].

The main criticism of these early models is the unacceptable low specificity or high number of false positive diagnoses. Clinically this would result in the operative intervention of seemingly suspicious yet sound tooth structure.

Collective results obtained from *in vitro* and *in vivo* studies, most of which have used histological validation, show that sensitivities range from 58-96 percent, and specificity 71-94 %[70,80 60,90,99,100].

In a recent study, performances of diagnostic systems were compared to each other using meta-analysis to facilitate the comparison of performances between each system. Nine *in vitro* studies and one *in vivo* study that complied with the criteria were included in the studies. The first study included teeth destined for fissure sealing indicated by fissure discoloration or enamel decalcification. Four readings were taken from each tooth in the first study[60] an only one reading was taken per occlusal surface in the other study[101]. The sensitivity and specificity values were converted to normal-deviate values and plotted. In both studies the best results were obtained by ERM under *in vivo* conditions[67].

Rock and Kidd[90] in an *in vivo* study compared the validity of five *in vivo* methods for caries detection with the histological appearance of the sectioned teeth. The Vanguard produced specificity values of 85% and sensitivity values of 70%.

In an additional study using a small child sample, drilling of the fissures was used as validation. Here it was demonstrated that ERM was more sensitive

than both clinical examination and radiography while the specificity was considerably lower than clinical examination but higher than radiography[60].

Many laboratory studies with histological validation have shown radiographic and electronic caries detection to be better than a visual examination alone[55,56,65,90,97,101-103]. Studies using electrical conductivity measurements of occlusal surfaces have shown to be more sensitive than the dental explorer[95] and traditional radiographic methods[104] in detecting early caries, when compared to results from tooth sectioning and histological examination.

Earlier models of this technique called the Electronic Caries Meter (ECM) now have a coaxial airflow incorporated into the tip to dry the tooth surface in the area where the measurements are taken. This should theoretically reduce the number of false positives that had been obtained with the superceded models. As mentioned earlier, false positive results may be obtained when the tooth is not properly isolated and is saturated with saliva. Other causes may include hypoplastic molars and newly erupted molars due to their lack of post-eruptive maturation[104]. However, it should be noted that these results are susceptible to confounding factors affecting the mineral content[3] and therefore conductivity of the sample tooth such as enamel hypoplasia or increases in pore volume of enamel due to lack of post eruptive maturation[104] will increase the number of false positives. In addition false negative results may be obtained with excessive drying of the tooth surface[104].

Although factors affecting *in vivo* results will not be found in *in vitro* studies, recent work[97] has suggested that there is a strong association between *in vivo* and *in vitro* ECM readings and that *in vivo* readings are repeatable. Results from an *in vitro* study demonstrated ECM to be the most repeatable system while achieving the highest combination of sensitivity and specificity compared with visual examination, FOTI, conventional and digital examination[80].

ERM can therefore be used as an accessory diagnostic technique in identifying occlusal enamel lesions that are confined to small enamel or early dentine lesions. Quantitative information may be provided in these cases. With obvious dentinal caries, minimal additional information would be provided over traditional radiographic methods where determination of the depth of the lesion will assist in operative intervention.

Light induced fluorescence

Fluorescence induced by laser light as a diagnostic method for early enamel caries detection was introduced in 1982[105]. With this understanding, many investigators have used fluorescence as a method for the quantification of progression, arrest, or regression of caries lesions of enamel and dentine and have given rise to the term "quantitative light-induced fluorescence", or QLF. Laser fluorescence with a low power argon laser is a repeatable, non-destructive technique that can quantify early mineral loss due to dental caries[106]. *In vivo* studies have shown that repeatability and reproducibility of the QLF method are very good[107].

Fluorescence occurs as a result of the interaction of electromagnetic radiation with both inorganic and organic tooth substances. Molecules are transferred to higher energy states when irradiated by light directed at it of suitable wavelengths, usually in the long wavelength (ultraviolet) and short wavelength (visible light). When the molecules fall from these excited states, a photon is emitted producing a colour of light corresponding to the energy given off. This light is referred to as fluorescence. It is accepted that the induced fluorescence of enamel is lower in areas of reduced mineral content, and that there is a relation between mineral loss and the radiance of fluorescence. It has been demonstrated that, in contrast to sound enamel which appears luminescent and fluoresces in the orange/yellow region of the spectrum, incipient and well developed carious lesions appear as dark areas when excited by laser light at

Inorganic and organic tooth substances absorb the laser. Therefore the instructions specify that the surface be clean because calculus and disclouration may give false values.

Some of the absorbed light from the DIAGNOdent is emitted as near infra red fluorescent light and, this increases as the carious lesion progresses[118]. The long pass filter absorbs the back-scattered excitation and other short wavelength light and transmits the longer wavelength fluorescent radiation. The display is registered both in real time and maximum value. The instructions suggest that numeric data between 5 and 25 indicate initial lesions in enamel and values greater than this indicates early dentine caries. Advanced dentine caries yields values greater than 35. The advantage of this system is that demineralisation can be detected and a quantitative readout is provided.

Ferrier Zandona 1998[66] conducted one of the few studies that has reported the use of LF on occlusal surfaces where sensitivity values of 0.49 and specificity values of 0.67 were achieved *in vitro*. The cut off limit was set at the enamel level and the inclusion of specimen teeth with more advanced caries would have likely increased the sensitivity and specificity scores.

A recent *in vitro* study[119] showed that reproducibility of the DIAGNOdent system in both the wet and dry of occlusal surfaces was excellent and diagnostic accuracy in terms of ROC analysis was significantly higher than for conventional radiographs. Higher Pearson's correlation coefficient values were found to be higher when the tooth was dry. Additionally the author believes that the values of the DIAGNOdent are more volume dependant as compared to lesion depth dependant as shown on the ROC curves. They reported that the instrument was very sensitive to stains, calculus deposits and any changes in the physical structure of the enamel such as hypomineralisation, all of which led to erroneous findings.

In a similar *in vitro* study with histological measures as validation, the DIAGNOdent was measured with electrical conductance methods [118]. The high sensitivities results of 76%-84% and specificities of 79%-87% of the DIAGNOdent were also reproducible, although the author noted that there were different degrees of learning between individuals. Nevertheless the authors still concluded that visual diagnosis remained the method of choice, and the DIAGNOdent could be used in occlusal sites of uncertainty.

Lussi and others[120] evaluated the DIAGNOdent system in an *in vivo* study. Surfaces of molars were examined visually after being air-dried. Clinical investigations using operative intervention as the gold standard have demonstrated that the DIAGNOdent device exhibited higher sensitivities at both the dentine and enamel cutoff level of 92 percent and 96 percent respectively (86% specificity), as compared to clinical inspection sensitivity of 31-62 percent and bitewing radiographs values of 63 percent. However the DIAGNOdent device was not able to distinguish clearly between deep dentinal caries and more superficial dentinal caries.

Little documentation exists for the measurement of enamel fluorescence with the red 655-nm diode laser light source used in the DIAGNOdent system. The design of the system is different to standard QLF as mentioned previously, and the basic research cannot be extrapolated from one technique to the other [121].

Principal limitations of these methods include QLF results only showing high correlations with the degree of demineralisation and not the degree of dentinal decay. Furthermore, the correlation of demineralisation is limited in depth [112,115,116]. The reported inability of the DIAGNOdent device to distinguish between superficial and dentinal decay *in vivo* [120], may be due to the inability of the laser light to reach the deeper dentinal layers.

Other limitations of this method are that clinical experience should be a fundamental prerequisite for using the instrument. Results of the DIAGNOdent are susceptible to clinical variations in technique. Factors affecting operator technique includes moisture isolation, lack of experience, and variations at which the tip is angled with respect to the occlusal surface. Tooth factors such as fissure morphology[31], enamel quality[106], staining calculus and plaque deposits[122], restorative materials, and remnants of polishing pastes may also alter the fluorescence and therefore cause false positives[106]. In addition to these clinical factors, methodological factors such as borderline and cut off values have been determined arbitrarily from unstructured observations which will play a part in the determination and decision making of operative intervention.

Promising results from *in vitro* studies may indicate a greater emphasis to be placed on QLF as a diagnostic tool for occlusal caries in the future, however further scientific scrutiny is required before it can be recommended for the definitive diagnosis of occlusal decay.

Conventional radiography

The usefulness of bitewing radiography in detecting approximal caries has been investigated[123]. Compiled data from five radiographic laboratory and *in vivo* studies of approximal caries validated by histology estimated a relatively low sensitivity value of 0.5, and a high specificity value of 0.93[124]. However comparisons of epidemiological studies show a discrepancy between the accuracy of radiographic techniques for approximal surfaces[123] and for occlusal surfaces[41,49]. In both, clinical judgments showed underestimations of dentine caries[35].

Bitewing radiography for occlusal surfaces has however, been considered of limited value for early caries diagnosis, possibly due to the anatomy of the

posterior teeth. The sound enamel of the surrounding cusps may mask any incipient demineralisation of the occlusal fissure[125]. A recent study has demonstrated that the validity of bitewing radiography in the detection of very early occlusal caries lesions is questionable and does not perform as well as other methods[60].

Mostly laboratory studies have shown that the sensitivity of radiographic caries diagnosis in occlusal surfaces has been found to be in the range of 0.4 and 0.67, with a relatively high value of specificity varying between 0.5 and 0.95[55,56,60,64,103,126-130]. Laboratory studies have shown that only 25% of lesions extending into dentine were detected by visual inspection, however this rate doubled to 50% when radiographical assessment was incorporated[55,65]. This low sensitivity value indicates that using bitewing radiography as a diagnostic tool is of limited value in detecting early caries lesions[61,124].

The clinician then is faced with balancing the risk and benefit and deciding whether the diagnostic yield for caries diagnosis is high enough to justify radiographic examinations. Hintz and Wenzel 1994[61] have questioned the practice of radiographic screening for low-caries-risk patients. A blanket regime of routine radiographic examination at fixed intervals cannot be recommended; individualized bitewing examinations should be determined on the basis of caries risk. However risk assessment is imprecise and risk status may change over time. Therefore radiographic intervals must be re-assessed regularly. No doubt there must be some benefit when radiographs are combined with a clinical examination as a basis for making individual treatment decisions[131]. It has been shown from clinical studies of children's teeth that radiographs will disclose more occlusal caries than the clinical examination. Fissures that were denoted as sound clinically were found to have radiographic caries[34,35,41,49,63]. Nevertheless, the use of different diagnostic thresholds in the studies make it difficult for comparison.

Given the changes in the morphology of caries, clinical examination and diagnosis of dentine caries have become less sensitive. The balance of risk and benefit indicates that the diagnostic yield for caries diagnosis is high enough to justify individualized examination frequencies while keeping in mind that all exposures must be kept as low as reasonably achievable.

Advantages in the use of bitewing radiography are in the detection of the progressed lesion that has proceeded beyond the DEJ. Although the results of *in vitro* experiments indicate that radiographs considerably underestimate the lesion size[21,103,132], bitewings are still useful for estimating the depth of the lesion[69] and assisting in operative intervention. The size of lesions at which the clinician elects to intervene restoratively is known as the "restorative treatment threshold". As the prevalence of caries rates and patterns have changed in recent decades, caries risk assessments are becoming more important to determine this threshold. It was previously thought that the optimal restorative threshold was when the radiolucency reached the enamel-dentine junction[83,133,134]. There are specific problems associated with treatment decisions associated with occlusal surfaces as compared to that of the interproximal radiolucencies due to the anatomy of the fissure system, orientation of the enamel prisms, complications introduced by the use of fissure sealants, the increasing awareness of hidden caries and as mentioned previously, the superimposition of cuspal enamel.

Digital radiography.

Most studies have so far evaluated the diagnostic performance of digital radiography in laboratory experiments and little information is available from clinical studies. Translation of the results of an *in vitro* model to an *in vivo* situation can be difficult, however a recent study has compared the laboratory and clinical results for radiographic caries diagnosis in the same teeth. It showed that the differences in diagnostic accuracy between the two situations were not

significant[135] so therefore laboratory diagnosis may correspond with clinical outcomes.

Additionally there are several systems available for image acquisition that make the direct comparison of results between studies complex. The indirect system involves the conversion of a film radiograph to a digital image, and is commonly referred to as digitization. This process is time consuming and the image quality deteriorates in the process of digitization.

The direct image plate system includes a re-useable phosphor photo simulation screen that stores photon energy when hit by an x-ray beam and emits light when scanned by UV light. The light is scanned and measured then stored in the computer as a digital image. Advantages of this system include automatic exposure control and low dose requirements of between 5 and 50 percent of the dose needed for conventional radiography to create an acceptable image[136].

The direct sensor system that includes a CCD (charge-coupled device) sensor, processor unit, a digital interface card, computer and software. The real advantage of the direct digital radiography system is the ability to display the radiographic image onto a monitor within a few seconds.

Of course, the advantage of all these systems over film-based radiography is the ability to manipulate the digital image to selectively present or discard the information. Processing includes digital image enhancement, subtraction radiography, automated image analysis and image reconstruction[136].

Wenzel 1988[137] found that high contrast in the radiographic image as compared to a radiograph that is too light was an important prerequisite to obtaining accurate results. Digital image enhancement can increase the contrast of the radiographic image without increasing the exposure. A study that

enhanced the digital images of low-density radiographs found that sensitivity increased by 20% without an increase in the number of false positive scores[65]. In fact, contrast enhanced digitized film and CCD based images performed better that non-enhanced images with the same system[138]. Other advanced digital techniques such as edge enhancement did not seem to lead to further improvement[138].

Subtraction radiography has been shown to be superior to conventional films mainly by reducing the amount of false positive scores[127,139]. It was also found to be useful for the visualization of remineralisation in an *in vitro* study[140]. Edge enhancement has so far been found to have no significant effect on diagnostic accuracy compared to conventional radiography while detecting caries on bite wings[141]. The accuracy of the image appears to be inversely proportional to the displayed size on the monitor because performance was reduced due to information being lost when the image was enlarged[142].

Although there may be a desire by the dental profession to adopt his new method, recent studies have yet to demonstrate convincingly the diagnostic differences between conventional radiography and digital techniques[143], and enhanced digital images[61 144] in the diagnosis of occlusal caries [55,92,127]. Of the few *in vitro* studies validated by histology that assessed efficacy of direct digital radiography, results have shown a range of sensitivities (19%-74%) and specificity values of 89 percent[50,80] indicating comparable to slightly better performance than conventional bitewing radiography[138].

Wenzel et al 1991[138] assessed the accuracy of digital imaging using indirect digital radiography and found that sensitivity increased in conjunction with an increase in false positive diagnoses. Wenzel et al 1991[55] compared digitized film images with the first direct digital CCD system and found no significant differences, although however paper print images were shown to be less accurate. Wenzel et al 1991[138] compared the detection of occlusal caries in

non-cavitated extracted teeth employing conventional film radiographs, digitized film radiographs and RadioVisioGraphy validated by histology. Slightly better performance was seen by the two digital methods with contrast enhancement. They concluded that any digital technique could improve the sensitivity without compromising the specificity.

Although few studies exist that clarify the relationship between the radiographic and clinical depth of the lesion, one study has found that there was a strong correlation between the two techniques and there was no evidence of underestimation with the histological depth [102]. Of the many laboratory studies, sensitivities for occlusal lesions extending into dentine ranged between 0.6 and 0.8[138].

The significance of digital radiography in occlusal caries diagnosis lies in the ease of image manipulation and also in the time saved from the elimination of processing procedures.

Conclusion

1. Many studies have used extracted teeth so that subsequent histological validation can be carried out. Limitations of these conditions provide a situation where recordings are static and represent a point in time. Caries is a dynamic process and diagnostic techniques should enable the lesion activity to be assessed over time. Therefore it is necessary to discriminate more precisely between the relevant theoretical considerations of each technique and the complicated process of diagnosis and treatment of individuals
2. The diagnostic information of each method is relevant to occlusal caries diagnosis. As no single method is ideal for this purpose, the cumulative information of several techniques will provide a clearer picture of both the presence and nature of the early occlusal occult caries. An understanding

of the unique features of each method will ensure that the clinician can use them to their best advantage.

3. The methods of visual inspection, electrical resistance measurement and quantitative light induced fluorescence are more suited to the diagnosis of early occlusal caries. Tactile techniques, fibre optic transillumination, conventional and digital radiography are less useful in this regard and are more useful in the diagnosis of more advanced and established dentinal lesions.

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Visual examination compared with conventional, digital radiography and DIAGNOdent® in the diagnosis of occlusal occult caries in extracted premolars.

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Abstract

Purpose: This laboratory study examined and compared the sensitivity and specificity of visual examination and manual probing compared to conventional, digital radiographs, and laser fluorescence in the detection of occlusal occult caries on extracted premolar teeth.

Methods: Extracted premolars without obvious caries or restorations were collected from school dental clinics. Occlusal surfaces of 320 extracted premolars were examined visually with an explorer then examined using the KaVo DIAGNOdent unit and scored using specific criteria. The teeth were exposed using conventional and digital radiography respectively. The radiographs were assessed for dentin radiolucencies beneath the occlusal surface. The results of the visual examination were correlated with those of other techniques.

Results: Of the 302 teeth scored as clinically sound in the study, 57 (19%) demonstrated dentine radiolucency on conventional bitewings and 245 (81%) scored as radiographically sound. The sensitivity of the clinical exam with conventional radiography was thus determined to be 0.81. In the teeth clinically scored as having caries 8 of the 18 teeth (44%) were found to have radiolucencies from radiography. Therefore the specificity of the clinical exam was determined to be 0.44. Compared to the clinical examination, the DIAGNOdent yielded 56% specificity and 89% sensitivity. Compared with conventional radiography the results of the data from the DIAGNOdent gave results of 91% specificity and 56% sensitivity.

Conclusion: The highest specificity of 67% was achieved with the combination of DIAGNOdent and conventional radiography in detecting occlusal caries. The highest sensitivity value of 98% was with the digital radiography when compared to conventional radiography. The least sensitive technique was found when the DIAGNOdent was compared to digital radiography and the least specific technique was the DIAGNOdent when compared to conventional radiography.

Introduction

The majority of clinicians use visual examination and the dental explorer in diagnosing if an occlusal surface is in need of restoration or if preventive management is required. Accurate diagnosis of the occlusal surface however, is difficult due to the anatomical nature of the fissures and the likelihood of caries being initiated on the fissure walls and base[1,2] which makes it difficult to detect with probing alone. For these reasons, occlusal caries may be missed clinically, yet the lesion may be diagnosed by radiographic means. The term occult "occult caries"[3] or "hidden caries"[4] are used to describe such lesions that are not clinically diagnosed but detected only on radiographs. The prevalence of occult caries has been reported to range from around 3% to over 50% in clinical studies[5-11]. The high prevalence of occult lesions suggests that traditional clinical methods using the mirror and explorer may be of questionable accuracy in the diagnosis of occlusal lesions.

Studies using histological validation show that only a small proportion of occlusal carious lesions can be discovered by visual inspection and probing[12,13]. Although it is known that conventional radiography is not sensitive in detecting early carious lesions which are limited to only enamel[14-16], conventional bitewing radiography in conjunction with visual-tactile examination has been shown to significantly improve the accuracy of occlusal caries diagnosis[17].

With the introduction of digital radiography in the 1990's more and more clinicians are replacing conventional radiography with the digital form. Nevertheless minimal data is available on the diagnostic differences between conventional radiography and digital techniques in the diagnosis of occlusal caries[15,18-23].

In recent years, laser fluorescence has been introduced as another technique for caries diagnosis[24] with the putative advantage of being able to quantify early mineral loss from dental caries[25]. Early reports using the KaVo DIAGNOdent suggest that the diagnostic performance of this new method has been found to be more accurate and reproducible compared with conventional radiography and clinical inspection[26,27].

In spite of the initial promising reports, the DIAGNOdent needs to be further validated with regard to its specificity and sensitivity as compared to other techniques.

The aim of the present study was to correlate clinical examination with conventional and digital radiography and laser fluorescence (DIAGNOdent) to determine their relative sensitivities and specificities in the diagnosis of occult occlusal lesions in extracted premolar teeth.

Methods

Selection of premolars.

A total of 320 extracted premolars were from School Dental Clinics. The extracted teeth for predominately orthodontic reasons. The extracted teeth were screened with respect to the presence of gross carious lesions, restorations or enamel hypoplasia / hypomineralisation defects ensuring that only those premolars with macroscopically intact occlusal surfaces were included in the study (table 1). Although varying degrees of fissure discoloration was present none of the teeth had visible approximal caries. The selected teeth were soaked in formalin immediately after extraction, rinsed in tap water and stored dry. The occlusal surfaces of the teeth were cleaned with a rotating bristle brush with pumice and rinsed in tap water and dried with a syringe. All clinical, radiographic and DIAGNOdent scores were taken by a single examiner (MC).

Table 1. Distribution of teeth by tooth-type.

Maxilla		Mandible		Total No
1st premolar	2nd premolar	1st premolar	2nd premolar	
(14) N=112	(15) N=0	(44) N=49	(45) N=0	161
(24) N=88	(25) N=18	(34) N=53	(35) N=0	159
total N= 200	total N=18	total N= 102	total=0	Total N=320

Visual assessment of premolar teeth.

The teeth were examined by visual inspection and Hu-Friedy* sickle explorer under standard dental lighting, without magnification, using clinical criteria in table 2. The teeth were thoroughly dried and the colour of enamel surrounding the fissures was noted with regard to whether demineralisation (opacity) was present. The clinical status of the occlusal surface was assigned the following scores according to whether demineralisation and cavitation were present. Afterwards light probing pressure was used to continue the assessment. A single operator performed the assessments in order to minimise operator variability.

* 3232 N.Rockwell St, Chicago, Illinois, 60618-5982

Table 2. Visual and probing criteria used in the clinical assessment of occlusal surface of premolars.

Clinical score	**Description**
C-0	No demineralisation or opacity present. Fissures not sticky
C-1	No demineralisation or opacity. Sticky fissures
C-2	Demineralisation or opacity present. Fissures not sticky
C-3	Demineralisation or opacity present. Sticky fissures
C-4	Frank cavitation larger than probe tip

Radiographic technique and assessment

Conventional film radiographs were exposed of the premolars. Periapical radiographs were performed using the Siemans radiographic unit* (70kV 70 mA) using size 22mm x 35mm Super Poly-Soft Kodak Ultraspeed film$^{\Psi}$ were used with an exposure time of 0.32secs, and processed manually according to the manufacturer's guidelines.

The radiographs were assessed by the author using no magnification and a standard radiographic illuminated viewing box, and peripheral light block out. The teeth were scored according to the depth of radiolucency present in dentine as based on the criteria in table 3. True occlusal radiolucencies were distinguished from buccal pits, which can show a vertical linear radiolucency. During the radiographic assessment of the premolars, the operator was blinded to the results of the clinical assessment.

* Siemans Aktiengesellschaft, Wittelsbacherplatz, D-8, Munchen 2, Germany.
$^{\Psi}$ Eastman Kodak Company, Rochester, NY, USA

Table 3. Conventional radiography scoring criteria.

Conventional radiography scores	**Description**
R0	No intracoronal radiolucency
R1	Radiolucency present within the crown (<1/3 dentine width)
R2	Radiolucency present within the crown (1/3-2/3 dentine width)
R3	Radiolucency present within the crown (>2/3 dentine width)

Digital Radiographic technique and assessment

The digital film radiographs were taken using the Sirona Heliodent DS* unit. Paralleling technique was used with teeth placed and held horizontal on a standard mount with dental wax. The film radiographs were recorded as 2cm x 3cm images. The teeth were exposed for 0.06 seconds.

Radiographs were assessed by the author using no magnification while being viewed on a Samsung SyncMaster 531TFT∞ LCD monitor with 1024x 768 pixels resolution, 24 bit colour. The teeth were scored using similar criteria as that used for the conventional radiographs looking at the presence and depth of dentine radiolucency present within the tooth crown. See table 4. True occlusal radiolucencies were distinguished from buccal pits, which can show a vertical linear radiolucency. During the radiographic assessment of the premolars, the operator was blinded to the results of the clinical assessment.

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* Sirona Dental Systems GmbH, Fabrikstrasse 31, D-64625 Bensheim, Germany.

∞ Samsung

Table 4. Digital radiography scoring criteria.

Digital radiography scores	**Description**
DR-0	No intracoronal radiolucency
DR-1	Radiolucency present within the crown (<1/3 dentine width)
DR-2	Radiolucency present within the crown (1/3-2/3 dentine width)
DR-3	Radiolucency present within the crown (>2/3 dentine width)

DIAGNOdent technique and assessment

Each occlusal surface was examined using the conical tip of the laser device of the KaVo DIAGNOdent laser fluorescence device[⊕] (figure 1). The tip was continuously rotated around a vertical axis until the highest reading was found (figure 2). Calibration was performed against a ceramic standard before each measurement. Readings were taken from a region of clean, sound tissue with no calculus or stains and the teeth were inspected dry.

Each occlusal surface was scanned and measured three times. The mean values of the three sets of data per tooth were recorded and then categorized according to the criteria as shown in table 5 and as suggested by the instructions. The occlusal surfaces indicating significant occlusal caries were photographed.

[⊕] KaVo Dental GmbH & Co. KG, Bismarckring 39, D-88400 Biberach/Riss, Germany.

Figure 1. Photograph showing DIAGNOdent unit used to examine teeth.

Figure 2. Photograph showing technique used with DIAGNOdent device.

Table 5. Scoring criteria and cut off values of DIAGNOdent results.

DIAGNOdent numerical value	Score	Description
Less than 5	L-0	No caries
Between 5-25	L-1	Enamel caries
Between 26-35	L-2	Dentine caries
Greater than 36	L-3	Advanced dental caries

Reproducibility of Intra-Examiner scores. (Table 6)

Reproducibility of the visual, conventional and digital radiographical scoring system was assessed using unweighted kappa statistic[28]. This was performed for nine teeth each of which was scored three times on three separate occasions. Kappa values of 0.4 and below denote marginal reproducibility. Scores from 0.4-0.75 denoted good reproducibility and kappa values above 0.75 denoted excellent agreements [28].

As shown in table 6, the Kappa statistic showed high scores of >0.80 for clinical, radiographic and digital radiographic examination. The scores ($p<0.001$) suggest high intra examiner consistency in the scoring.

Statistical analysis

The data were analysed by a statistician (DP) using the SAS for windows, Version 8.2 computer program. The Spearman Correlation Coefficient was used to compare different techniques. Mantel-Haenszel Chi- squared tests were used to determine the significance of sensitivity and specificity values.

Table 6. Intra-examiner variability for the clinical assessment of premolar teeth, expressed by the weighted Kappa statistic[28].

Diagnostic technique	Weighted Kappa value
Clinical	0.83
Conventional radiography	0.82
Digital radiography	0.92

Results

A total of 320 premolars were examined. Of these 218 (68%) were premolars and 102 teeth (32%) were mandibular premolars. (Table 1)

All the premolars in the sample had no obvious caries, occlusal malformations or any restorations. The individual results of the clinical assessments of the 320 teeth were correlated against the results of conventional and digital radiographic assessment and DIAGNOdent.

Clinical examination and conventional radiography

As shown in table 7, out of the 320 teeth examined, 302 (94%) were scored as clinically sound. Of these, 272 (90%) were scored as having no opacity and fissures not sticky, and 30 (9%) were scored as having no opacity/ demineralisation, though with sticky fissures. Of the remaining 18 teeth scored as having caries, all 18 teeth were thought to have demineralisation with no sticky fissures.

Radiographically, 256 (80%) teeth did not exhibit a radiolucency within the tooth crown, 59 (18%) teeth had radiolucency less than one third the dentine width of the crown and only 5 (1.5%) showed dentine radiolucency extending to within one-third to two-thirds the dentine width. The most frequent diagnosis was therefore a combination of clinically sound teeth with no demineralisation/ opacity, no sticky fissures and absence of occlusal dentine radiolucency (69% of the total teeth). There were no teeth that had dentine radiolucency greater than two-thirds of the dentine width of the crown.

As shown in table 7, the results of clinical assessment were correlated against the results of the radiographic assessment. Of the 302 teeth scored as clinically sound (C0-C1), 57 (19%) demonstrated dentine radiolucency on conventional bitewings (R1-R3) and 245 (81%) scored as radiographically sound (R0). The sensitivity of the clinical exam with conventional radiography was thus determined to be 0.81.

In the teeth clinically scored as having caries (C2-C4), 8 out of the 18 (44%) were found to have radiolucencies within the crown as seen on bitewing radiography (R1-R3). Table 7. Therefore the specificity was 44%. Spearman correlation coefficient S_p= 0.10 (95% CI: -0.024, 0.224). The Spearman's correlation (S_p) measures the correlation between two different variables where +/-1 are the greatest value and the value 0 representing no correlation. This correlation coefficient value of 0.1 indicated that there was a minimal correlation between the data obtained from the clinical examination and conventional radiography. Chi-squared (χ^2) test for association χ^2= 6.75 (on 1 df), p= 0.0095. This indicated that there was only a small association between these two variables.

Table 7. Correlation of clinical visual scores with conventional radiography.

Clinical scores	R-0 (N)	R-1 (N)	R-2 (N)	R-3 (N)	Total no.
C0	221 (69% of total teeth)	48 (15%)	3 (1%)	0	272 (85%)
C1	24 (7.5%)	6 (2%)	0	0	30 (9%)
C2	11 (3%)	6 (2%)	2 (0.6%)	0	18 (6%)
C3	0	0	0	0	0
C4	0	0	0	0	0
Total (N)	256	59	5	0	320

Table 8. Correlation of clinical scores with digital radiography.

Clinical scores	DR-0	DR-1	DR-2	DR-3	Total no.
C0	247 (77%)	25 (8%)	1 (0.3%)	0	273 (85%)
C1	27 (8%)	3 (1%)	0	0	30 (9%)
C2	10 (3%)	7 (2%)	1 (0.3%)	0	17 (5%)
C3	0	0	0	0	0
C4	0	0	0	0	0
Total (N)	284	35	2	0	320

Clinical examination and DIAGNOdent assessment.

As shown in table 9, the individual results of clinical assessment of the 320 teeth were correlated against the results of the DIAGNOdent assessment. Clinically, out of the 320 teeth, 302 teeth were scored as clinically sound. Of these 272 (85%) teeth were scored as having no demineralisation or opacity and having no sticky fissures, and 30 (9%) teeth were scored as having sticky fissures though no demineralisation or opacity. There were no teeth scored clinically as having sticky fissures and demineralisation/ opacity or having frank cavitation larger that the probe tip.

The DIAGNOdent scores showed that none of the teeth received a score of D-0 indicating no caries. The majority of the teeth, 278 (87%) received a score that indicated enamel caries, 23 (7%) teeth had a score indicating dentine caries and the remaining 19 (6%) teeth indicated advanced dentine caries. There were no values from the DIAGNOdent that indicated that the teeth were caries free.

The most frequent diagnosis was the combination of clinically sound occlusal surface with no opacity or demineralisation and DIAGNOdent readings indicating enamel caries.

Results with the DIAGNOdent showed that of the 302 teeth that scored as clinically sound, 278 (92%) teeth had a reading of no caries or early enamel caries on the DIAGNOdent (L0-L1), thus giving a sensitivity of 92%. When the teeth with clinical caries (C2-C4) were considered, 10 out of the 18 teeth gave DIAGNOdent readings greater than 26 (L2-L3) suggesting that the specificity of DIAGNOdent in diagnosing the carious lesions was only 56%.

Results from table 8, show that the values from the DIAGNOdent indicate that a higher proportion of teeth have dentine caries as compared to those shown by conventional radiography. However the DIAGNOdent did not diagnose any sound teeth. It can be seen that there are a higher proportion of values obtained indicating caries present, compared to the values obtained from conventional radiography. It may be assumed that the DIAGNOdent is more sensitive than conventional radiography.

Spearman correlation coefficient $S_p = 0.307$ (95% CI: 0.164, 0.449). Chi-squared (χ^2) test for association $\chi^2 = 24.63$ (on 1 df), $p < 0.001$.

Table 9. Correlation of clinical scores and DIAGNOdent values.

Clinical scores	D-0	D-1	D-2	D-3	Total no.
C0	0	248 (76%)	11 (3%)	13 (4%)	272 (85%)
C1	0	22 (7%)	5 (1.5%)	3 (1%)	30 (9%)
C2	0	8 (2.5%)	7 (2%)	3 (1%)	18 (5.6%)
C3	0	0	0	0	0
C4	0	0	0	0	0
Total (N)	0	278	23	19	320

Conventional radiography and digital radiography

As shown in table 10, the individual results of the conventional radiography and digital radiography were correlated.

Results with the digital radiography showed that of the 258 teeth that scored as radiographically sound (R-0), 254 (98%) teeth also had a reading of no intracoronal digital radiolucency (DR-0), thus giving a sensitivity of 98%. When the teeth with intracoronal radiolucencies were considered, 33 out of the 62 (53%) teeth gave digital radiographic readings (DR1- DR3), suggesting that the specificity of digital radiography in diagnosing carious lesions was 53%.

Spearman correlation coefficient S_p= 0.64 (95% CI: 0.538, 0.749). Chi-squared (χ^2) test for association χ^2= 140.95 (on 1 df), $p < 0.001$.

Table 10. Correlation of conventional radiography and digital radiography.

Conventional Radiography	Digital R- 0	DR- 1	DR- 2	DR- 3	Total no.
R-0	254 (79%)	4 (1%)	0	0	258
R-1	30 (9%)	27 (8%)	1 (0.3%)	0	57
R-2	0	4 (1%)	1 (0.3%)	0	5
R-3	0	0	0	0	0
Total	284	35	2	0	320

DIAGNOdent and conventional radiography assessments

As shown in table 11, the individual results of the DIAGNOdent assessment of the 320 teeth were correlated against the results of conventional radiography.

Of the 320 teeth, 238 (74%) teeth were found to have received a score of L-1 from the DIAGNOdent unit indicating early enamel caries. The remaining 82 (26%) teeth scored as having dentine caries. Of these 82 teeth, 63 (20%) teeth were indicated to have dentine caries and the remaining 19 (6%) teeth were indicated to have advanced dentine caries.

Of the 238 teeth scored on the DIAGNOdent as either sound or having early enamel caries (L0- L1), 196 (82%) teeth were radiographically sound (R0). The sensitivity of the DIAGNOdent technique was found to be 82%. In the teeth scored as having caries with the DIAGNOdent (L2-L3), 55 out of 82 teeth were found to have radiolucencies within the crown as seen on bitewings (R1-R3). Therefore the specificity of the technique was determined to be 67%.

Spearman correlation coefficient S_p= 0.444 (95% CI: 0.334, 0.553). Chi-squared (χ^2) test for association χ^2= 42.82 (on 1 df), p< 0.001.

Table 11. **Correlation of DIAGNOdent values and conventional radiography.**

DIAGNOdent values	R0	R1	R2	R3	Total no.
D0	0	0	0	0	0
D1	196 (61%)	41 (13%)	1 (0.3%)	0	238
D2	14 (4%)	46 (14%)	3 (1%)	0	63
D3	13 (4%)	5 (1.6%)	1 (0.3%)	0	19
Total	223	92	5	0	320

DIAGNOdent and digital radiography

As shown in table 12, the results of DIAGNOdent assessment of the 320 teeth were correlated against the results of the digital radiographical assessment.

Results with the digital radiography showed that of the 289 teeth scored as sound on the DIAGNOdent (L0-L1), 263 (91%) teeth had a reading of no intracoronal radiolucencies on the digital radiography (DR0), thus giving a sensitivity of 91%. When the teeth with caries, as assessed by the DIAGNOdent were considered, 11 out of the 41 (27%) teeth gave radiographic readings (DR1-DR3). This suggests that the specificity of digital radiography in diagnosing carious lesions was only 27%.

Spearman correlation coefficient S_p= 0.18 (95% CI: 0.040, 0.320). Chi-squared (χ^2) test for association χ^2= 6.155 (on 1 df), p=0.013

Table 12. Correlation of DIAGNOdent values and digital radiography.

DIAGNOdent values	DR0	DR1	DR2	DR3	Total no.
D0	0	0	0	0	0
D1	263 (91%)	25 (8%)	1 (0.3%)	0	289
D2	14 (4%)	7 (2%)	1 (0.3%)	0	22
D3	16 (5%)	3 (1%)	0	0	19
Total	293	35	2	0	320

Comparison of technique for sensitivity and specificity

Figure 3 shows the comparative sensitivities and specificities of the various combinations of techniques

Clinical examination and conventional radiography

As shown in figure 3, the sensitivity of the clinical examination with conventional radiography was 81% and the specificity of the technique was determined to be 44%.

Clinical examination and digital radiography

As shown in figure 3, the sensitivity of the clinical examination with digital radiography was 94% and the specificity of the technique was determined to be 47%.

Clinical examination and DIAGNOdent

As shown in figure 3, the sensitivity of the DIAGNOdent with clinical examination was 89% and the specificity of DIAGNOdent in diagnosing the carious lesions was only 56%.

Conventional radiography and digital radiography

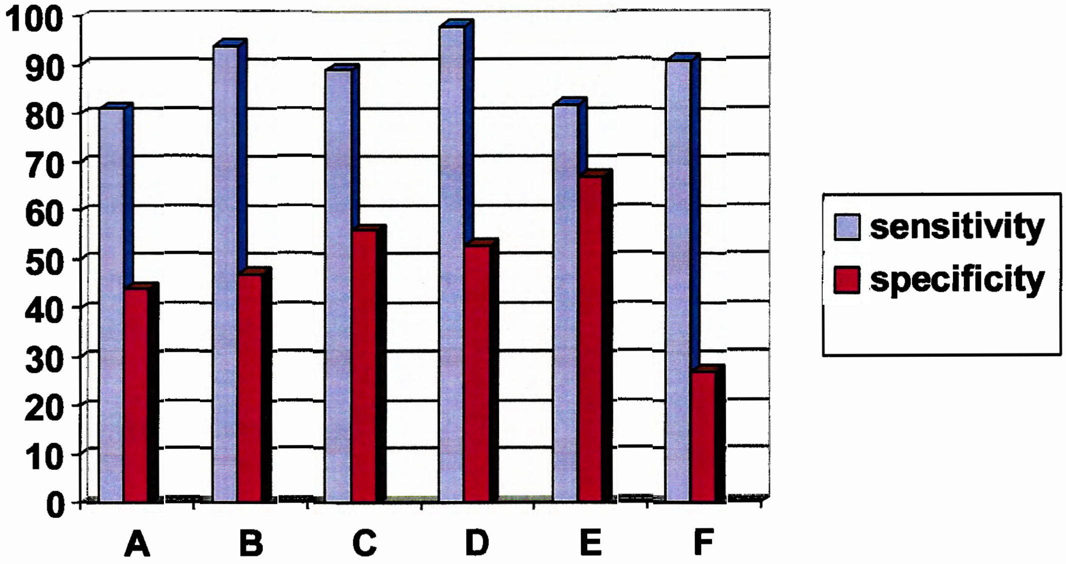
As shown in figure 3, the sensitivity of conventional radiography with digital radiography was 98% and the specificity of digital radiography in diagnosing the carious lesions was only 53%.

DIAGNOdent and conventional radiography

As shown in figure 3, the sensitivity of the DIAGNOdent with conventional radiography was found to be 82% and the specificity of the technique was determined to be 67%.

DIAGNOdent and digital radiography

As shown in figure 3, the sensitivity of the DIAGNOdent with digital radiography was found to be 91% and the specificity of the technique was determined to be 27%.



A- Clinical examination and conventional radiography

B- Clinical examination and digital radiography

C- Clinical examination and DIAGNOdent

D- Conventional radiography and digital radiography

E- DIAGNOdent and conventional radiography

F- DIAGNOdent and digital radiography

Figure 3. Comparison of technique for sensitivity and specificity.

Table 13. Sensitivities, specificities and Spearman correlation (non-parametric) of the results obtained.

Diagnostic technique	Specificity%	Sensitivity %	Spearman correlation coefficient S_p (95%CI)
Clinical examination and conventional radiography	44	81	S_p=0.10 (-0.024, 0.224)
Clinical examination and digital radiography	47	94	S_p=0.1663 (0.025, 0.308)
Clinical examination and DIAGNOdent	56	92	S_p=0.307 (0.164, 0.449)
Conventional radiography and digital radiography	53	98	S_p=0.6433 (0.538, 0.749)
DIAGNOdent and conventional radiography	67	82	S_p=0.444 (0.334, 0.553)
DIAGNOdent and digital radiography	27	91	S_p=0.18 (0.040, 0.320)

Discussion

As occlusal caries now represent a large majority of the caries found in children[29-31], it is of increasing clinical importance that occult lesions are detected accurately to prevent the further progression of disease into the tooth structure.

In this laboratory study of 320 extracted premolars, we compared and correlated the sensitivities and specificities of the results from different diagnostic techniques available.

In our comparison of visual examination and conventional radiography, we found a sensitivity value of 81% and specificity value of 44% (table 13). The sensitivity value for clinical examination that was found in this study was considerably higher than those achieved by other authors[12,14,21,22,27,32-38]. However our results did compare to the results of two other investigators. Ekstrand and co workers[39] achieved sensitivity and specificity values of >92% and >85% respectively in a laboratory study of extracted molars which were validated histologically (table 14). The reason for their high values may be attributed to the meticulous visual inspection that incorporated visual ranked caries scoring system modified from their previous study[40]. Although this system appears promising in its application for clinical use, one limitation is that this method takes time to learn and teeth surfaces must be clean and dried thoroughly.

Table 14. Sensitivities and specificities of varying diagnostic systems from 18 *in vitro* studies and two *in vivo* studies.

Author	Diagnostic system	Validation	Sample	Enamel Sens	Enamel spec	Dentine Sens	Dentine spec
Ashley et al 1998[32]	Visual Radiographic	Histological	Ext molars	0.6 0.19	0.73 0.8	0.24 0.24	0.97 0.89
Ashley et al 2000[33]	Visual Radiographs	Histological Histological	Prim molar Prim molar			0.45 0.93	1 0.89
Ekstrand et al 1997[39]	Visual Radiographic	Histological Histological	Ext molars Ext molars			0.92-0.97 0.51-0.56	0.85-0.93 1
Huysman et al 1998[34]	Visual Radiographic	Histological Histological	Ext M/PM Ext M/PM			0.27 0.5-0.66	1 0.83-0.91
Kay et al 1988[35]	Visual	Histological	Ext molars			0.57	0.67
Ketley& Holt 1993[36]	Visual Radiographic Visual Radiographic	Histological Histological Histological Histological	Ext molars Ext molars Prim Molar Prim Molar			0.31 0.67 0.45 0.93	0.98 0.92 1 0.89

Author	Diagnostic system	Validation	Sample	Enamel Sens	Enamel spec	Dentine Sens	Dentine spec
Lussi et al 1999[26]	DIAGNOdent	Histological	Ext molars			0.76-0.84	0.79-0.87
Lussi et al 2001[27]	Visual Radiographic DIAGNOdent	Cavity prep Cavity prep Cavity prep	*In vivo* *In vivo* *In vivo*			0.31 0.63 0.92	-- 0.99 0.86
Russell &Pitts 1993[41]	Radiography (D speed) Radiography (E speed) radiovisiogra	Histological Histological Histological	Ext M/PM Ext M/PM Ext M/PM			0.18 0.21 0.21	0.98 0.99 0.97
Shi et al 2000[24]	DIAGNOdent	Micro-radiographic	Ext M/PM	0.42-0.46	0.95	0.78-0.82	1
Verdonschot et al 1992[14]	Visual Radiography	Cavity prep Cavity prep	*In situ* *In situ*			0.13 0.58	0.94 0.66
Verdonschot et al 1993[37]	Visual Radiography	Histological Histological	3rd molars 3rd molars			0.49 0.61	0.89 0.79

Wenzel et al 1990[42]	Visual Radiography Digital rad (DRe)	Histological Histological Histological	Mol/premol Mol/premol Mol/premol			0.8 0.75 0.8	0.87 0.9 0.88
Wenzel et al 1991[21]	Visual Bite wings Digital (DRe) xeroradiog	Histological Histological Histological Histological	Ext molars Ext molars Ext molars Ext molars			0.2 0.4 0.74 0.4	0.97 0.98 0.89 0.9
Wenzel et al 1991[20] (RG detectn)	Bite wings Digital (DRe) Digital (DRe) radiovisiogra (contrast enhancement)	Histological Histological Histological Histological	Ext molars Ext molars Ext molars Ext molars			0.62 0.72 0.62 0.69	0.85 0.83 0.83 0.84
Wenzel & Fej 1992[38]	Visual Radiographic Digital (DRe) Digital (DRe)	Histological Histological Histological Histological	3rd molars 3rd molars 3rd molars 3rd molars			0.54 0.48 0.71 0.54	0.81 0.81 0.85 0.77
Wenzel et al 1992[22]	Visual Radiographic Digital(DRm) Digital (DRr)	Histological Histological Histological Histological	Ext molars Ext molars Ext molars Ext molars			0.34 0.49 0.47 0.46	0.97 0.94 0.86 0.9

Wenzel et al 1990[42] achieved sensitivity and specificity values of 80% and 87% (table 14) respectively on extracted molars and premolars with histological validation. A likely reason for the relatively high values of their sensitivity results may lie in the differences of their sample selection. The inclusion of teeth with large open cavities was likely to have a significant positive effect on their results compared to studies that only included teeth with intact occlusal surfaces and no obvious carious lesions.

Although the results of the sensitivity values in this study seem promising, it should be considered that while the other studies used histological validation we effectively used the conventional radiography as validation for the clinical inspection. This would have positively influenced the results because using conventional radiography as validation would result in some carious lesions being missed as compared to the histological sectioning.

The combination of visual inspection and conventional radiography is one of the most common combinations used in clinical practice to diagnose caries. A sensitivity value of 81% indicates that 19% of the teeth that were scored as clinically sound had demonstrated dentine radiolucencies on conventional radiography. When compared to the relatively high prevalences reported in a few studies[5-11] this value is modest for several reasons. Firstly, other studies were validated histologically compared to the conventional radiographical validation used in this study. Occlusal dentine lesions do not appear as distinct dentine radiolucencies on conventional radiographs[14,39] possibly due to the superimposition of sound cuspal tooth structure.

Secondly laboratory conditions allow for more accurate visual inspection of the occlusal surface. A dry tooth surface has a greater difference in the refractive index between sound and demineralised tooth, therefore it is easier to detect the lesion. The beneficial results of air drying occlusal tooth surfaces for visual inspection has been demonstrated by Ekstrand and co workers[17,39,40,43,44].

Thirdly the inclusion of visual inspection into the criteria for clinical examination as compared to probing alone was included into the criteria for clinical inspection because the accuracy of probing alone is questionable due to variations in the interpretation between operators[45]. The "light pull" that is often associated with a carious fissure is dependant on factors such as pressure exerted, the path of insertion and withdrawal and the fissure anatomy[13,46,47]. Therefore in an attempt to limit the amount of false positive findings usually associated with probing, our criteria for stickiness on probing was combined with the visual appearance of opacity/ demineralisation. Excellent results of visual inspection alone has been achieved by Ekstrand and coworkers[39,40,43,44] in evaluating occlusal caries in molars.

There has been limited support for the use of the dental probe in diagnosing caries, due to the potential danger of transmitting *Streptococcus mutans* from infected to uninfected fissures[48]. Additionally Ekstrand and coworkers[49] showed the damaging effects on demineralised enamel caused by the use of an explorer when examining of fissures. This has been shown to increase the rate of formation and growth of the lesion[50]. Of more importance are the unreliable and poor sensitivity scores achieved in studies[13]. In fact Lussi 1991[12] achieved lower sensitivity results from dentists using an explorer than those without an explorer in an *in vitro* study comparing the diagnostic accuracy and reproducibility of explorers of occlusal caries.

In the present study we extended previous work by correlating clinical examination with conventional radiography and laser fluorescence (DIAGNOdent) to determine their relative sensitivities and specificities in the diagnosis of occult occlusal lesions in premolar teeth. From our study, the results from the comparison between DIAGNOdent and conventional radiography for sensitivity and specificity values were 92% ($p<0.001$) and 55% ($p<0.001$) (table 13). The sensitivity values are marginally better compared to other laboratory

reports[24,26](table 14). These results achieved by the DIAGNOdent *in vitro* for the detection of occlusal decay should theoretically be better than those achieved clinically for various reasons.

Extracted teeth are more likely to be cleaner than teeth examined in the clinical setting because they are stored in formalin and pumiced thoroughly. Furthermore selected teeth with staining, calculus, and enamel hypocalcification defects were excluded from the study, thus the potential for erroneous readings and false positives from these defects were minimised[27,51].

Studies have shown that different values of fluorescence from light induced studies can change the dehydration of the tooth[52]. As the teeth in our study were stored dry, the results may differ from those obtained clinically. On the other hand, the consistent degree of hydration obtained from laboratory investigations provides better standardization of the technique.

However Lussi and coworkers[27] have achieved excellent results from their *in vivo* study using the DIAGNOdent unit with operative intervention as validation. Air-dried occlusal surfaces of molars and premolars were examined visually and radiographically (when available) and with the DIAGNOdent device. They reported a sensitivity of 92% and specificity of 86%. However this sensitivity was based on a population of teeth with a high prevalence of caries, since only those teeth that appeared clinically and which required operative intervention were assessed for the presence of decay. Additionally, the examiners in the study were experienced users of the machine and special emphasis was placed on air-drying the surface to be inspected. Other authors have noted that clinical experience is a fundamental prerequisite for using the DIAGNOdent unit to accurately detect clinical caries[24,26,51].

The **55% specificity** achieved by our study was noticeably less than those achieved by the same authors where the range achieved for specificity was 79%-100%[24,27,53] (table 14).

This value indicates that 45% of the sample teeth clinically scored as having caries did not register as carious on the DIAGNOdent. One likely explanation for this difference in sensitivities between the current and previous studies may be due to differences in the cut-off limits between studies. The cut-off limit used by Lussi et al 1999[26] was markedly lower than the cut off criteria used in their study. This would have effectively reduced the sensitivity and increased the specificity achieved by Lussi and coworkers[26]. One problem with comparing the results of studies using the DIAGNOdent device is that recognized cut-off limit guidelines are not yet established and have so far been loosely based on histological evaluation. Consequently caution is required in extrapolating these cut-off limits to the clinical situation and further work is needed in this area. Cut-off limits developed by Shi and co workers [24] was established using receiver operating characteristic (ROC) curves and analysis make it difficult to compare the two criteria.

Additionally the inclusion of probing criteria may have contributed to the number of false positives gained. These reasons for this occurrence have been discussed previously.

"Quantitative light-induced fluorescence", or QLF may provide an alternative technique with the advantage of providing quantitative diagnostic information. The importance of this tool is in its longitudinal monitoring of caries and demineralisation and assessing the outcome of preventive interventions. *In vivo* studies have shown that repeatability and reproducibility of the QLF method are very good[54]. Its value lies in its use of facilitating other methods of occlusal caries diagnosis in cases of clinical uncertainty for a second opinion. Laser fluorescence demonstrates significant improvements over established diagnostic

methods, particularly with regard to sensitivity, specificity and reproducibility. As is the case of other diagnostic methods, single measurements taken with the DIAGNOdent cannot discriminate between active and inactive lesions. However knowledgeable clinical judgment based on the patients history, visual cues, and review of radiographs is still a necessity for the provision of making informed diagnostic judgments.

The sensitivity and specificity of digital radiography alone was not assessed in this study however digital radiography was used as a technique to validate other diagnostic methods such as clinical examination and the DIAGNOdent device. The sensitivity and specificity of clinical examination and conventional radiography were 81% and 44% respectively. When digital radiography was used to validate clinical examination the results of sensitivity and specificity was 94% and 47% respectively. Therefore the results are quite similar with only a marginally higher sensitivity achieved with the use of digital radiography as compared to conventional radiography. Other studies have found no significant difference between film radiography and RadioVisioGraphy[18].

When comparing the performances of the DIAGNOdent with conventional and digital radiography as validation, sensitivity values were fairly similar with values of 82% and 91% respectively. However the specificity value obtained when digital radiography was used was only 27% (the lowest sensitivity achieved of all techniques) compared with 67% for DIAGNOdent and conventional radiography. Therefore this would indicate that a greater number of radiolucencies were diagnosed radiographically (73%) when the DIAGNOdent scored the same occlusal surface as sound.

These results may signify that in this study the digital method for radiography was more sensitive. Although recent studies have yet to demonstrate convincingly the diagnostic differences between conventional radiography and digital techniques in the diagnosis of occlusal caries, *in vitro* studies that were

validated histologically have shown slightly better performance than conventional methods with regards to sensitivities and specificity values[20-22,32,38,45].

The highest Spearman Correlation (S_p =0.64) was achieved from the comparison of conventional and digital radiography. This was expected, as the two modalities of diagnosis were the most similar, hence obtaining the most agreement between results. Since both methods are inaccurate in detecting occlusal caries, their high correlation combined with a sensitivity of 98% and specificity of 53% indicates that the two methods would be not be ideal in the screening of caries. Consequently, although both methods will agree with the diagnosis of caries, by the time the diagnosis is made, the demineralisation would have progressed into dentine, necessitating the need for operative intervention instead of conservative procedures such as invasive fissure seals.

The comparison of DIAGNOdent and conventional radiography achieved the next best correlation with a S_p = 0.44. This value indicates a healthy correlation between the two diagnostic methods. Our study achieved a sensitivity value of 82% which is similar to the results achieved by other studies[24,26,27]. The DIAGNOdent unit has demonstrated good sensitivities and specificities by othe r *in vitro* studies[24,26] of early occlusal caries. Additionally the quantifiable nature of the results will allow the early occlusal caries to be monitored longitudinally and assessed after preventive intervention such as topical fluoride[25].

Conclusion

In conclusion, the highest specificity of 67% was achieved with the combination of DIAGNOdent and conventional radiography in detecting occlusal caries. The highest sensitivity value of 98% was with the digital radiography when compared to conventional radiography. The least sensitive technique was found when the DIAGNOdent was compared to digital radiography and the least specific technique was the DIAGNOdent when compared to conventional radiography.

The results of this study imply that the commonly used methods of clinical examination and conventional radiography did not achieve good results in regards to the correlation of between their results and specificity value achieved when diagnosing occlusal caries in premolars. The inaccuracies of probing in the clinical detection of occlusal caries are well documented and it would seem plausible to discard this technique except for the purpose of removing debris from the fissures. Additionally the limitations of conventional radiography to detect incipient occlusal caries also must be considered when used in isolation. Therefore we may question the time-honoured method of these techniques as valid diagnostic tools.

With good correlation scores and comparatively good results for sensitivity and specificity, two pairs of combinations performed well.

The DIAGNOdent and conventional radiography achieved the best correlation scores behind conventional and digital radiography and had also achieved the highest specificity score. The combination of clinical examination and DIAGNOdent achieved the next best correlation score and also achieved a high sensitivity result. The use of these techniques should theoretically improve the accuracy of the diagnosis of occlusal caries. The three methods discussed above are all easily accessible, quick, non-destructive and easily tolerable for the patient and are recommended.

Additionally it can be assumed that the greater number of diagnostic techniques that are employed, the greater the accuracy the findings will be. Therefore, the use of the three techniques of clinical examination and visual inspection, conventional radiography and the DIAGNOdent unit used in combination should improve the results achieved of traditional methods.

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